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Discontinuities in Physical Systems and especially Fluids have been studied from the points of view of Scientific modelling, numerical analysis, simulation and software.

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Final Report

Shock Wave Calculations

I Introduction

A number of fluid problems and other physical systems are dominated by the presence of strong discontinuities. These discontinuities often play an important role in the understanding and accurate computation of the solution to such problems. The research of this contract was directed at this problem as a whole and included scientific modelling, numerical analysis, computer simulation and development of software.

The physical test problems studied were gas dynamics and oil reservoirs.

II Scientific Modelling

The work in scientific modeling was centered on studies of Riemann problems. Many computational methods for solving gas flow problems are based on approximating the problem with a number of more elementary flow problems called Riemann problems. The solution of Riemann problems are important because they provide an explicit and elementary class of solutions which contain extensive information about wave interactions. They are the basic constructive step in the random choice method, and they provide the key input into the methods based on front tracking.

The solutions of Riemann problems for flows influenced by curved geometry exhibit, as characteristic phenomena, a strengthening or weakening of the waves. They may contain waves completely missing when there is no curvature. Such effects arise, for instance, in one dimensional flows with variable cross-section and flows with cylindrical and spherical geometry. Two dimensional flows with curvilinear coordinattes produce the same effect. For conservation laws describing gas dynamics there is a nonlinear coupling of the modes of propagation, so that as a shock in a given mode changes strength, it emits signals which propagate in other modes, leading to secondary waves.

The purpose of [12,13] is to assess the benefits and difficulties of including curvature effects in the Riemann problem solutions. For this purpose we studied gas flow in Laval nozzles using a generalization of the random choice method.

Point sources in the Riemann problems produce new waves. They represent a novel method to include the effect of lower order terms, both for scalar equations and for systems. The Riemann solutions for certain 2 x 2 systems were studied including gas dynamics, black oil and surfactant flow.

For bona fide two dimensional wave interactions such as regular reflection and Mach reflection patterns, a literature study was performed.

III Numerical Methods

The research of this project has required the development of new numerical methods. The principal accomplishments of this type are the numerical slution of Riemann problems, the development of front tracking, the acceleration of iterative solutions of elliptic problems and the construction of efficient adaptive grids.

The front tracking is the method used to resolve discontinuities [8]. It requires the use of Riemann problems to determine the speed of propagation of the discontinuity. Riemann problems for isothermal gas dynamics were solved numerically [14]. Some Riemann problems in oil reservoirs with commonly occuring but mathematically complex features were considered. For two dimensions, wave interactions lead to regular reflection and Mach reflection patterns, which can be regarded as the elementary waves in a two dimensional Riemann problem. The use of shock polars is essential in solving these two dimensional wave patterns. In the case of regular reflections, preliminary results were reported in [16].

IV Simulation

Fingering of an oil water interface was studied by the front tracking method. As far as we can tell from a study of the literature, the front tracking method offers an order of magnitude improvement in resolution on this problem. Many other methods are unable to obtain fingers at all. Our methods allow a study of the formation and growth of fingers including an analysis of statistical properties [3,4,5,6,7,8].

The gas dynamics calculations were both one and two dimensional. In one dimensional calculations, shock waves in a pipeline [14] spherical waves and Laval nozzles [13] were studied. These one dimensional calculations were a test of ideas important to two dimensions, specifically the role of source terms and of singularities introduced by curved wavefronts.

The two dimensional calculations in gas dynamics are still in a preliminary stage. The problems studied are: circular waves, Helmholtz instability and regular reflection of shock waves [16]. These preliminary results show considerable promise.

V Software

Software packages have been developed for the tracking and manipulation of multiple fronts or interfaces, and in work associated with this project but supported elsewhere, for elliptic equations, utilities and graphics. Considerable effort has been dovoted to ensure the generality of these packages, which are still in evolution due to the complexity of the Computer Science issues involved.

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